Dinoflagellate blooms on the surface ice of Blue Lake, Snowy Mountains, Australia

Mainland Australia's five natural snow-fed alpine lakes that regularly freeze over the winter are located in the Snowy Mountains (36° 25'S). Ice formation on these lakes usually occurs in June, close to the winter solstice, and the date of ice break-up is usually in October (Green 2011). Over the past decade the extent and thickness of ice on Blue Lake has been measured in early to mid-September. Layering in the ice was documented as overlaying snow, hard ice layers and slush layers, and monitoring of the ice cover was continued until ice break-up. Highly conspicuous red colouration on the ice cover was observed in October 2002, 2003 and 2004 but (for various reasons such as ice breakout in September 2006, heavy October snowfalls obscuring the lake ice surface in 2009) no colouration was seen between 2005 and 2010 (Table 1). Red colouration was seen in November 2003, when the ice lasted until then, but was never seen in September. Samples were collected in October and November 2003 and were preserved in gluteraldehyde for examination with a scanning electron microscope at the Australian Antarctic Division.

The organism causing the red staining on the lake ice surface (Fig. 1) was identified as a dinoflagellate, probably *Glenodinium* sp., although a definitive identification would require the appliction of molecular biology (Harvey Marchant, pers. comm. 2012). Dinoflagellates constitute a large proportion of marine phytoplankton communities and are responsible for red tides or algal blooms in coastal areas. However, freshwater red tides caused by dinoflagellates do occur, generally in waters that are moderately rich in nutrients, particularly in reservoirs (Fukuju *et al.* 1998). The most famous regular summer blooms occurred in Lake Tovel (Italian Alps) and were thought to be due to *Tovellia sanguineum* (previously *Glenodinium sanguineum*) (Cantonati *et al.* 2003). However, the processes within the lake attributed to *T. sanguineum* were actually caused by three different species of dinoflagellates (Calliari *et al.* 2004).

Table 1. The occurrence of red staining on the surface ice of Blue Lake, together with September ice thickness and ice break-up date from 2002 to 2011.

Year	September ice thickness (cm)	Ice break -up (Julian day of year)	October Staining?
2002	92	294	Yes
2003	89	316	Yes
2004	194	296	Yes
2005	73	294	No
2006	45	264	No
2007	39	294	No
2008	136	285	No
2009	91	307	No
2010	202	303	No
2011	112	296	Yes

Of the dinoflagellates in freshwater, many are cryophilic (cold loving). In Lake Tovel the presence of *T. sanguineum* is limited generally to periods of ice cover, but can occur until late spring or early summer with highest abundance during winter or spring (Calliari *et al.* 2004). *Peridinium euryceps* from Lake Erken (Sweden) also appears during winter underneath the ice (Rengefors and Meyer 1998). Dinoflagellates also occasionally stain snow on land and two records from the European Alps pre-date the first record from Canada in 1971 (Gerrath and Nicholls 1974). Microbial communities including dinoflagellates in sea ice are well studied (Thompson *et al.* 2006) whereas accounts of similar communities within the ice of freshwater lakes are rare (Felip *et al.* 1995). Reports of dinoflagellates include colouring the surface of the ice on Lake Davos in 1916 (Gerrath and Nicholls 1974), and their occurrence in the slush ice of various Pyrenean and European Alps lakes (Felip *et al.* 1995), but this is the first such collection from the ice surface of an Australian lake.

Ice cores from Blue Lake show layering of the ice. This is caused by the mass of falling snow forcing the initial hard water-ice layer beneath the hydrostatic layer, allowing lake water to mix with the surface snow to form slush, before the

surface of this also freezes, forming a further hard ice layer (Green 2011). The layers of slush ice, possibly enriched with nutrients from snowfall and windblown debris, provide the basis for the inoculum of microbial species from the lake water to grow once light becomes available, as it does when the surface snow thaws in spring. The top-down melting of the ice cover helps to concentrate the dinoflagellates in slush on the lake ice surface. In the years 2002-2004, staining was widespread across the surface of the lake ice but concentrated around cracks in the ice. In 2011, after a heavy snowfall at the end of September, there was no widespread staining because the snow lasted well into October; instead, the dinoflagellates appeared to be concentrated along cracks in the ice.

Dinoflagellates in freshwater environments, whether open water or ice, are uncommon. Their appearance on lake ice for such a short period in October, and not in all years, added to the possibility that they are cryophilic and present in the water column at other times of the year in only very low numbers, means that research on them must, of necessity, be opportunistic.

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Fig. 1. Red staining on surface ice of Blue Lake by dinoflagellates in October 2011. The avalanche probe reading nearest the camera shows 70 cm.